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Integrated Operations / Payloads / Fleet Analysis Final Report Executive Summary

Prepared by ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

February 1972

Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

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INTRODUCTION

The Integrated Operations/Payloads/Fleet Analysis predicts total national space program costs and launch vehicle traffic assuming either an expendable, a partially reusable or a fully reusable launch vehicle fleet. The payload system costs are estimated and reported for each payload program at the subsystem level, payload program level, user level and national level, providing complete system cost traceability. The analysis determines the primary changes to be expected for space payload programs and space operations in the Space Shuttle era. When the Space Shuttle becomes fully operational, not only will launch costs be reduced but refurbished satellite units will be flown instead of new units and maintenance will be performed on failing satellites.

It is possible to implement the concepts of satellite refurbishment and maintenance because of the Space Shuttle's capability to retrieve and return payloads to the earth's surface. The two-way satellite transportation capability is extended to high energy orbits by use of the Space Shuttle/Space Tug combination.

This analysis was accomplished in the winter and spring of 1971. The preliminary results were reviewed, checked and modified in the summer of 1971. The space activity assumed in the 1980's for this analysis has a launch rate comparable to a similar period in the 1960's and incorporates NASA's and DoD's best available space system plans.

The national space system plans for the 1980's were almost exclusively for expendable launch vehicle payload systems. A major portion of the effort in the Integrated Operations/Payloads/Fleet Analysis was to adapt these plans to Space Shuttle/Space Tug operations.

The Integrated Operations/Payloads/Fleet Analysis grew out of an analysis a year earlier by Mr. Robert N. Lindley, NASA Headquarters. As required by OMB, Mr. Lindley's analysis was extended to obtain an industry-based, detailed study which also included a Payload Effects Analysis by Lockheed Missiles and Space Company (LMSC) and an Economic Benefits Analysis by Mathematica, Incorporated.

In addition to assisting NASA to fulfill the OMB requirement, the Integrated Operations/Payloads/Fleet Analysis developed data which show the value of adapting payload program plans and developments to the Space Shuttle system at the earliest possible time. These data also show the direction and activities which NASA and other users should consider when adapting payload programs to the Space Shuttle/Space Tug system. This Executive Summary is addressed primarily to the findings relative to the value in adapting payload programs to the Space Shuttle.

TRAFFIC

SCHEDULED PAYLOAD TRAFFIC

Scheduled payload traffic was furnished by NASA for each payload program (see Table 1). With the exception of the NASA Observatory and the NASA Space Station Programs, payload launch schedules furnished were for expendable payloads. The Observatory and Space Station traffic included revisits, logistics resupply and eventual return of flight hardware to the ground. Five hundred sixty three of 653 payloads launched are automated spacecraft.

Because of the Space Shuttle's retrieval capability, whenever a cost reduction results from satellite refurbishment on the ground, expendable satellites can be replaced by reusable satellites and Shuttle flights for satellite retrieval added. Of the 58 automated satellite programs analyzed, payload retrieval flights were added to 45 (78 percent). In addition, 4 satellite programs scheduled revisit flights. In all, 54 of the 78 payload programs analyzed realized cost savings due to satellite reuse.

The large number of reusable payloads flown on the Shuttle is shown in Table 2. One hundred sixty nine of the 533 reusable satellite launches are payload units being launched for the first time. All of these payloads are refurbished an average of over two times through 1990, where the analysis stopped. Most payloads would continue to be reused beyond 1990. Payload retrieval did not change the payload costs for planetary missions.

Satellite reuse in this analysis included:

1. Reuse of a retrieved satellite which was completely refurbished.
2. Reuse of a satellite whose mission equipment or experimental equipment had been replaced by newly developed mission equipment and experiments. The spacecraft or remaining portion of the satellite was completely refurbished.
3. Reuse of a satellite on which all subsystems had undergone equipment replacement or update with newly developed equipments. This update is referred to as a satellite model change.

The applicability and schedule for these three types of satellite reuse varied with the payload objective, payload and program lifetimes and estimates of rates of advancement for technology. For instance, a test vehicle program is supplied with newly developed experiments for nearly every flight while an operational satellite system would be supplied with newly developed mission equipment only every five to ten years.

The LMSC Payloads Effects Analysis furnished data on three typical satellites adapted to the Space Shuttle. The LMSC adaptation of satellites included not only the design for maintainability and refurbishment already discussed, but also incorporated low cost design principles, such as ruggedized structure at the expense of satellite weight and volume to achieve lower satellite costs when appropriate. The low cost design principles were found to be economically advantageous for 31 percent of the satellite programs (see Table 2).

UNSCHEDULED PAYLOAD TRAFFIC

Unscheduled payload traffic resulted from:

1. Reflight of a payload returned safely to the launch site after Shuttle or Tug abort.
2. Reflight of a payload retrieved and returned after an early payload failure or serious anomaly, sometimes referred to as payload infant mortality.
3. Flight of a backup or replacement payload in case of premature payload loss or failure for an expendable payload.

Projections of failure data into the 1980's showed that approximately one-half percent of Shuttle flights would abort with safe return, two percent of the Tug flights would abort, three percent of the expendable launch vehicles would fail to reach their destination and six percent of the payloads would suffer infant mortality. The net result was a savings in direct costs of about seven percent with payload retrieval. The largest portion of the savings is due to re-orbiting a repaired satellite instead of a new satellite.

SPACE SHUTTLE FLEET TRAFFIC

Space Shuttle traffic for transporting the scheduled and unscheduled payload traffic is shown in Figure 1. The Shuttle buildup flight rate data (1979-1981) was supplied by NASA. The payloads not accommodated by the Shuttle in these years are orbited by expendable launch vehicles.

The launch vehicle traffic for the DoD support missions is included in the traffic and cost analyses even though costs could not be estimated for the payload traffic. The average Space Shuttle launch rate for the fully operational system is 63 launches per year. The following information summarizes the results of the traffic analysis during the Space Shuttle era, exclusive of the DoD support missions.

1. After the Shuttle and Tug are fully operational, approximately 58 percent of the flights include a reusable Space Tug.

2. Multiple payload launches reduce the number of Shuttle flights required. Payload retrieval increases the number of Shuttle flights required. The net result is a reduction in total number of Shuttle launches relative to payload launches of 16 percent.

3. The average Shuttle load factor by weight is 80 percent on the way to orbit.

4. Unscheduled Shuttle flights average 3.5 per year or about 6 percent of the launches.

5. There appears to be ample opportunity for small self-deployed piggyback Shuttle orbit payloads of opportunity.

Table 1. Scheduled Payload Traffic

	79	80	81	82	83	84	85	86	87	88	89	90	Total
NASA													
Physics and Astronomy*	6	8	10	10	10	14	13	13	14	15	16	14	143
Earth Observations	1	3	4	6	4	2	3	4	7	4	2	3	43
Comm. and Navigation	7	6	6	5	7	7	4	5	6	6	6	4	69
Planetary	3	1	1	4	0	1	3	1	1	1	1	2	19
Space Station	0	0	9	6	8	7	12	11	10	9	8	10	90
NASA TOTALS	17	18	30	31	29	31	35	34	38	35	33	33	364
NON-NASA													
Communications	3	5	8	3	6	3	3	6	7	6	4	4	58
Navigation	3	2	3	0	2	0	2	0	2	0	2	0	16
Meteorology	2	2	2	2	2	2	2	2	2	2	2	2	24
Earth Resources	4	0	4	0	4	0	8	0	0	4	6	0	30
NON-NASA TOTALS	12	9	17	5	14	5	15	8	11	12	14	6	128
NON-MILITARY TOTAL	29	27	47	36	43	36	50	42	49	47	47	39	492

* Includes Revisits

Table 2. National Payload Programs and Scheduled Traffic Summary, 1979-1990
Space Shuttle Fleet, Tug Available 1979

AGENCY	PAYLOAD TRAFFIC				PAYLOAD PROGRAMS		
	Total	Payload Revisits	Reusable Payloads	Expendable Payloads	Total	Low Cost Design	Current Design
NASA	364	62	249	53	52	20	32
NON-NASA	128	0	128	0	9	1	8
DOD	161[1]	0	156	5	17[1]	3	14
TOTAL	653	62	533	58	78	24	54

(1) Not including support missions

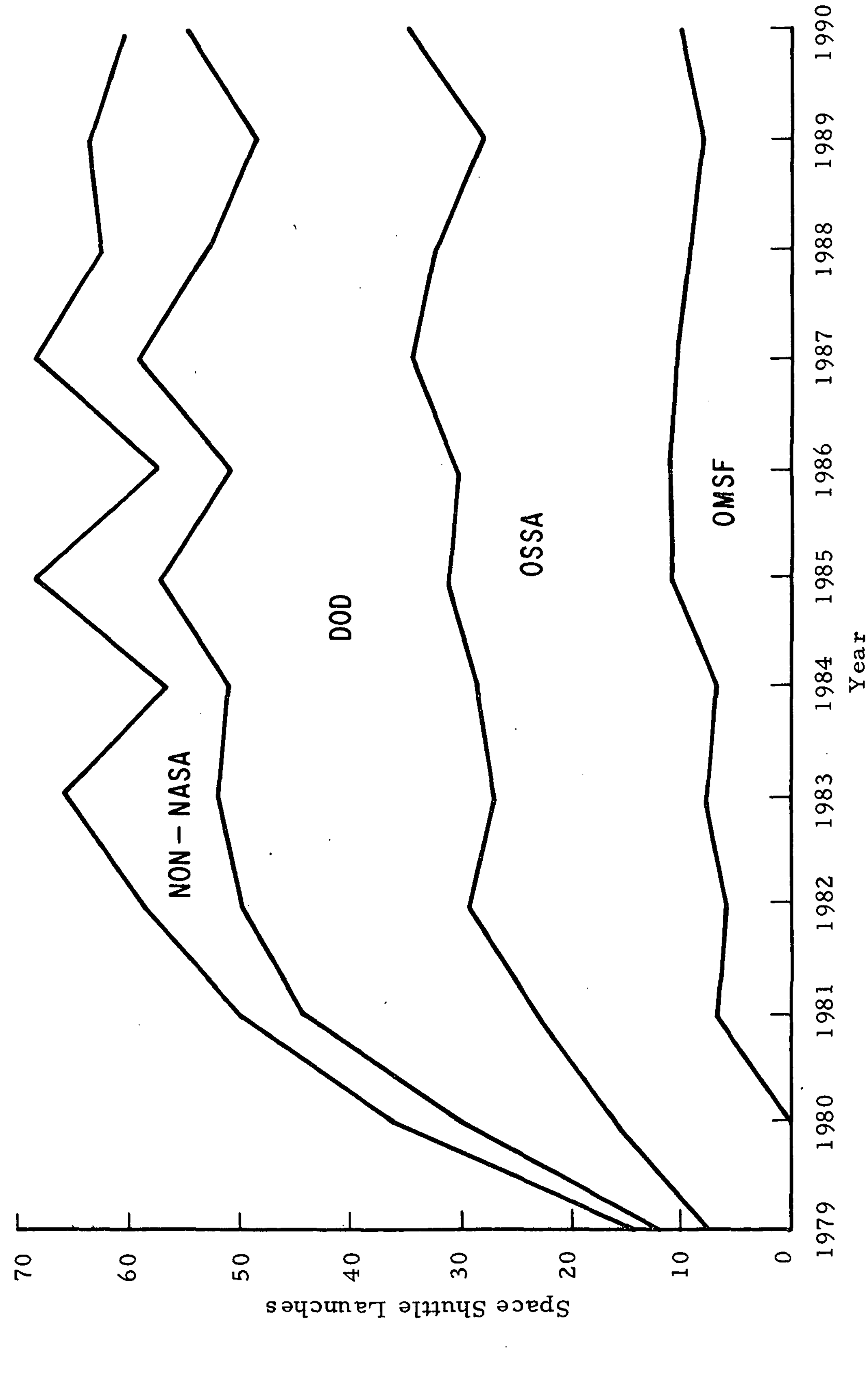

Figure 1. Space Shuttle Traffic

COST ESTIMATES

Cost estimates are based on historical cost data for completed NASA and DoD hardware development and procurements. Parameterized cost accounting data from aircraft, missile and launch vehicle programs are applied in estimating launch system costs. Parameterized cost accounting data from 14 payload procurements is the basis for payload cost estimates. The system cost estimates include all costs to the government (or commercial user) except for the agency institutional base costs. Costs could not be reliably estimated for the NASA space station hardware or the DoD support missions and are excluded from this analysis. Estimates based on historical costs automatically include overruns and cost increases due to program delays.

The national non-military space program direct cost estimates are compared for operations on expendable and Space Shuttle launch vehicle fleets in Figure 2. Direct costs include costs for all phases of the payload program, including launch charges.

The Space Shuttle used in this analysis is a 4.6 million pound, fully reusable system accommodating a 15 foot diameter, 60 foot long payload. Each launch is estimated to cost 4.4 million dollars. The new expendable launch vehicle fleet with the lowest cost payload mix (best mix) saves approximately 170 million dollars per year. The Space Shuttle with the best payload mix is estimated to save an average of 1.02 billion dollars per year for the non-military users. The corresponding average yearly savings for the DoD is 0.39 billion dollars. The total of 1.41 billion dollars per year savings does not include the potential savings for the DoD support mission payload effects. The cost savings are due to:

	% of Savings
Lower Launch Costs	43
Increased Launch Vehicle Reliability	3
Payload Retrieval and Reuse	49
Low Cost Payload Design	5

Payload retrieval and reuse cost savings due to the reflight of refurbished payloads and repaired payloads instead of new payloads is the largest cost savings driver identified. Ten percent of the 49 percent savings for retrieval and reuse is due to retrieval of satellites suffering infant mortality failures.

The 2 billion dollars per year average direct costs for all users in the Space Shuttle era are composed of:

	% of Direct Costs
Payload RDT&E	32.5
Payload Investment	17.0
Payload Operations and Refurbishment	35.5
Launch Costs	15.0

Of this 2 billions, 1.3 billions per year is the estimated NASA direct cost. An average of 950 million per year is estimated for NASA automated spacecraft programs.

If additional savings are to be realized, new approaches are needed to reduce: (1) payload development costs, such as standardization and utilization of developed hardware, and (2) payload refurbishment costs, such as long life, highly maintainable and refurbishable spacecraft designs and optimizing scheduled and unscheduled maintenance of satellites.

For a 50 percent increase in Space Shuttle launch costs, from 4.4 million dollars to 6.6 million dollars, the yearly savings due to the Space Shuttle decrease only 10 percent. The Space Shuttle savings are surprisingly insensitive to launch costs.

The manned space flight activity analyzed is a Space Station Program. Cost estimates for the Space Station Program were made on resupply flights and laboratories but not on the space station modules themselves. The space station activity accounts for 18 percent of the yearly cost of space operations and is therefore a minor part of the analysis.

On Figure 2, the effects of delaying the introduction of the Space Tug into the Space Shuttle Fleet from 1979 to 1985 is shown. Agena and Centaur upper stages are used until the Tug is available. The economic impact of the delay has been minimized by developing reusable satellites, for those satellites requiring a transfer stage, before the Tug is introduced. Payload retrieval and reuse can thus be introduced at the earliest possible date after 1985. The Tug retrieves satellites launched on Agena and Centaur upper stages prior to 1985.

The value to the national space program of the reusable Tug with satellite retrieval capability was estimated. Once the Tug is fully operational, its use reduces the average yearly direct costs by approximately 500 million dollars compared to the alternative of flying expendable Agena and Centaur upper stages on the Shuttle Fleet.

Effects of the Space Shuttle on the Polar Earth Resources Payload Program costs are shown in Figure 3. The Polar Earth Resources Program is scheduled to initiate operations in 1979 of a system having four satellites in orbit. With the Shuttle Fleet, the four satellites launched in 1979 and two of the satellites launched in 1981 are new units. All of the remaining satellites launched are reused units. New satellite mission equipment is developed and procured for flight in 1983 resulting in the second funding peak. The third funding peak is due to the six launches scheduled for 1989. Typically the funding peak due to payload RDT&E costs is reduced 23 percent due to the use of the LMSC low cost payload design approach, including reductions in payload test hardware. Payload investment costs are reduced after the initial procurement of satellite units. Launch costs are somewhat lower but payload operations costs increase due to payload refurbishment resulting in an overall program cost decrease of over 50 percent during the operating period for the satellite systems.

The lower peak funding estimated for Space Shuttle satellite programs improves the ability to fit new program starts into a given budget level.

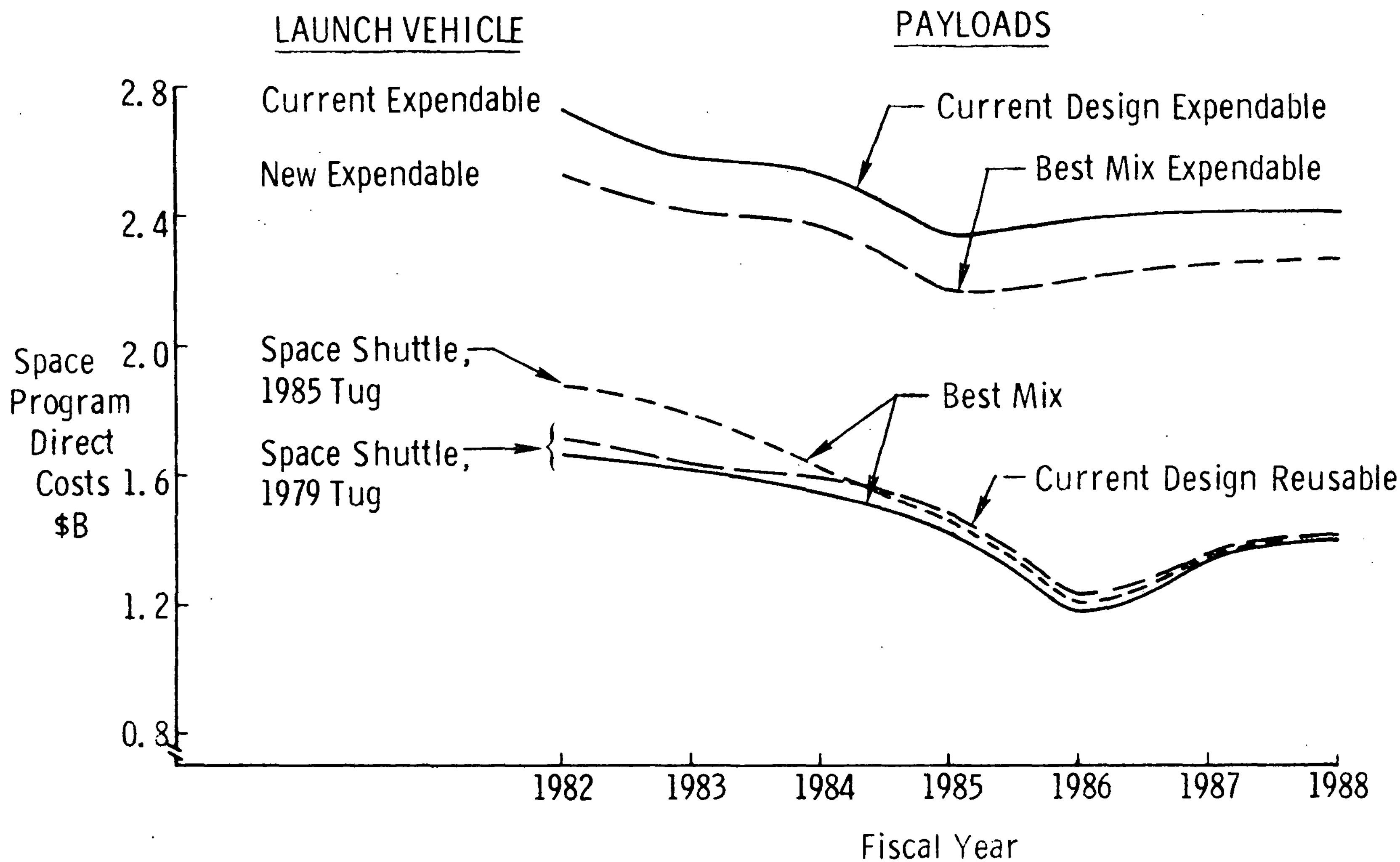

Figure 2. NASA and Non-NASA Space Program Direct Cost Comparisons, 1970 $

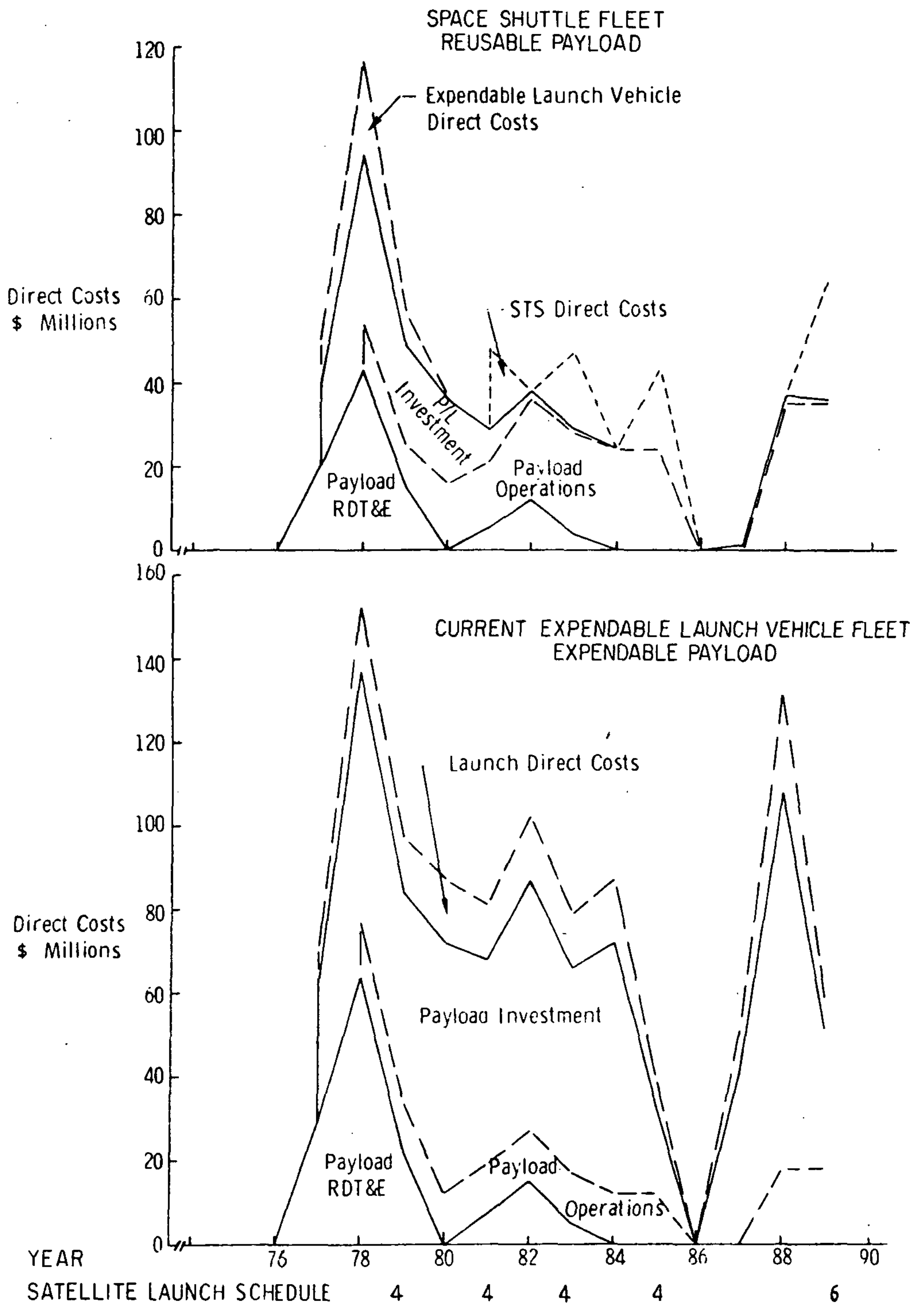

Figure 3. Polar Earth Resources Funding, 1970 Dollars

SUMMARY OBSERVATIONS

The Integrated Operations/Payloads/Fleet Analysis assumes that any new space system will have to be competitive to be approved; that is, a new launch system or a new payload system must be economically advantageous compared with the established or alternate ways for carrying out the proposed function. The plans, definition and operation of the new system will be driven toward minimum system cost and minimum peak year costs by this process. Using this assumption, the cost tradeoffs made in this analysis result in the prediction of several changes in the character of space systems in the Space Shuttle era. Satellites will be refurbished, repaired, maintained, updated and then reused. Very few, if any, payloads will be lost due to launch vehicle or payload failures. Therefore, instead of a payload procurement that is either continuous or periodically reactivated throughout the life of a satellite system, as is experienced today, the initial payload procurement will provide the required hardware capability for the system. If technology improvement or system requirements justify changes in the satellite hardware during the system lifetime, these changes will be made on the satellites at the same time satellite maintenance or refurbishment is carried out.

The emphasis in this analysis is largely on the transportation of automated payloads. Manned flight in the form of a Space Station Program is a minor portion of the economic analysis. Short term (7 day) manned sortie flights were not treated in economic comparisons but can be a valuable and important element in the future.

Space Shuttle cargo bay size and payload weight-carrying capability can markedly affect the Shuttle utility, economics and efficient operation. Smaller payload bay sizes will impact the ability to apply the LMSC payload effects and will require additional Shuttle flights to perform the same payload programs. In the limit, smaller Shuttle payload bay dimensions preclude the use of a Tug and therefore the ability to deliver and retrieve payloads in high energy orbits.

Launch costs are the least sensitive elements of the analysis; RDT&E costs for the Shuttle and payloads, and refurbishment cost of payloads are the principal drivers.

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